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FLIGHT EVALUATION OF WIDE-ANGLE, OVERLAPPING MONOCULARS FOR PROVIDING PILOT'S FIELD OF VISION

by Paul L. Chenoweth and William H. Dana

Flight Research Center
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FOR PROVIDING PILOT'S FIELD OF VISION

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SUMMARY

A qualitative evaluation was made of the effectiveness of wide-angle, overlapping monoculars as the sole source of outside visual reference during takeoffs, aerial maneuvers, visual navigation, and approaches and landings in a light observation aircraft. The evaluation was made during the day and at night and in air conditions which varied from no turbulence to severe turbulence.

The monoculars provided pilot visibility that was adequate for gross control of angle of pitch and angle of sideslip and precise control of bank angle. When used in conjunction with an altimeter and airspeed indicator, the optics gave the pilot enough information with which to satisfactorily perform takeoffs, visual navigation, mild aerial maneuvers, and power-off approaches through the landing flare. The system was as suitable for outside visual reference during night operation as during the day and was satisfactory for flight in light and moderate turbulence.

INTRODUCTION

A major problem in the design of orbital vehicles is the provision of adequate direct visual reference for the crew. Whereas a wide field of view is required for maneuvering and landing after reentry, the weight of adequate viewport glass and associated heat shielding is incompatible with vehicle weight constraints. A possible solution to this problem was investigated in a flight program at the NASA Flight Research Center, Edwards, Calif. Wide-angle optics were mounted in a light observation aircraft to provide the sole source of outside vision for the evaluating pilot. Takeoffs, visual navigation, aerial maneuvering, and approaches and landings were performed and qualitatively evaluated using this apparatus for visual contact.

This paper presents the results of the aerial evaluations with the optics. Results of preliminary ground tests are presented in the appendix.

DESCRIPTION OF APPARATUS

Optics

The optical system tested consisted of two wide-angle, overlapping monoculars. The system was developed by Farrand Optical Co., Inc., under a contract with the U.S. Army for evaluation in armored vehicles. The monoculars are constructed as straight tubes, each providing a 90° circular field of vision that is linear and of unity power. The exit pupil is 15 millimeters in diameter and located 25 millimeters from the final lens surface. Figure 1 is a photograph of the optical system. The image quality and a more complete description of the system are presented in reference 1.

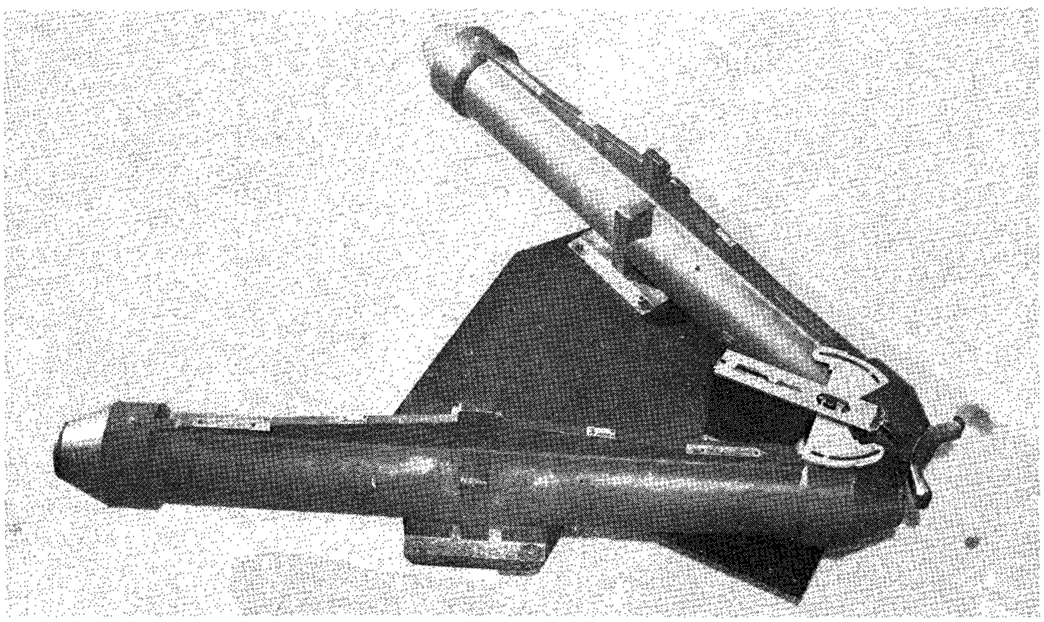

Figure 1.- Optical system. E-10652

Airplane

An Army O-1A light observation airplane (fig. 2) was selected as the test vehicle because it required minimum structural modification to accommodate the optical system. The airplane is a single-engine, tandem-seat, high-wing monoplane with flight controls in each cockpit.

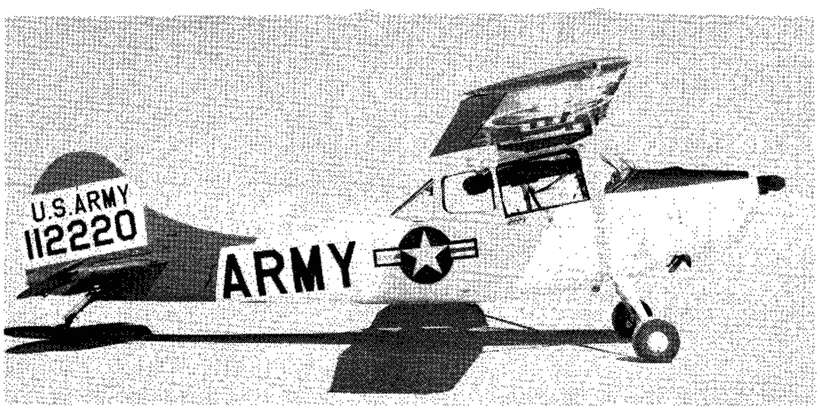

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Figure 2.- Test airplane.

Installation

The monoculars were mounted in the rear cockpit of the test airplane on a structure added specifically for their support (fig. 3). The monocular axes converge toward the evaluation pilot at an angle of 55°. This separation was the minimum allowed by the geometry of the installation and closely approached the maximum separation permitted by the geometry of the optics and the separation (60°) selected as optimum in a preliminary ground evaluation (see appendix).

Two inclinations of the optical system were investigated: level with the fuselage reference axis, as shown in figures 2 to 4; and depressed 17.5°, as shown in figure 5. The 17.5° depression was the maximum allowed by the mounting structure.

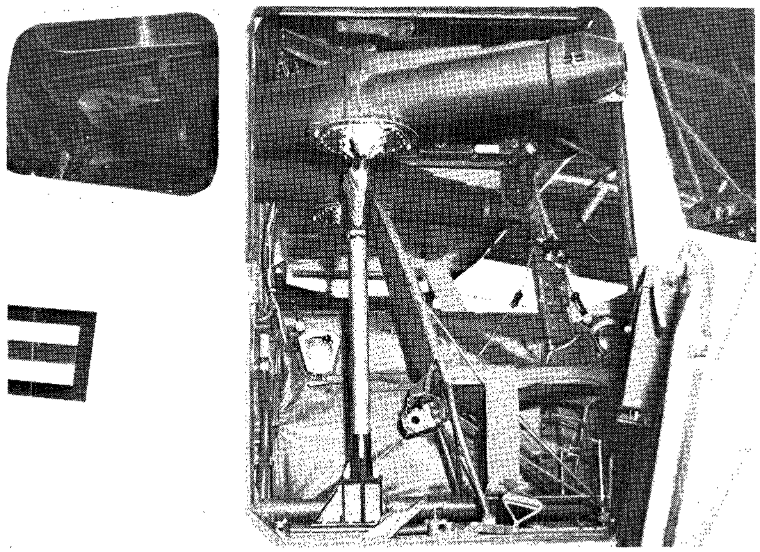

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Figure 3.- Monocular supporting structure in the test airplane.

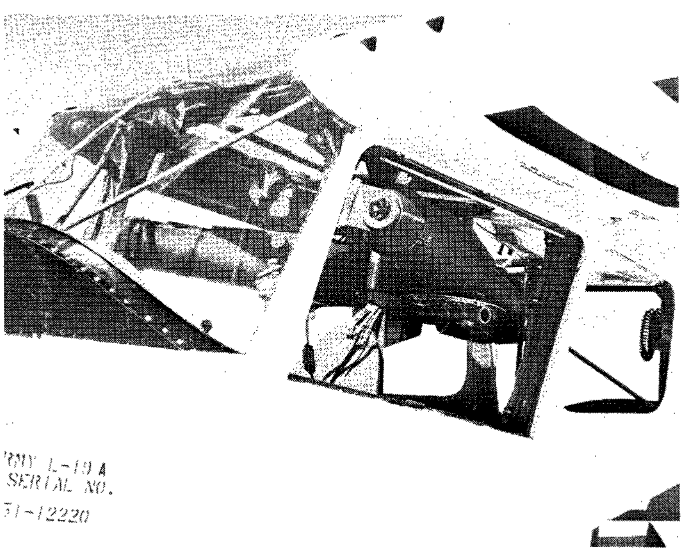

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Figure 4.- Location of monocular exit lens in the test airplane.

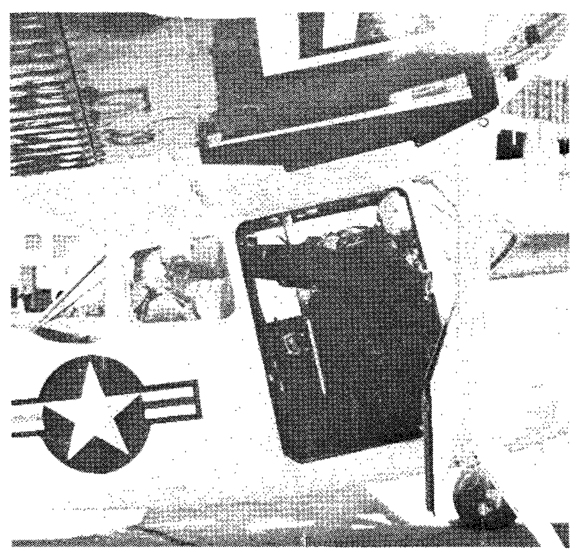

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Figure 5.- Monoculars depressed 17.5° from fuselage reference axis.

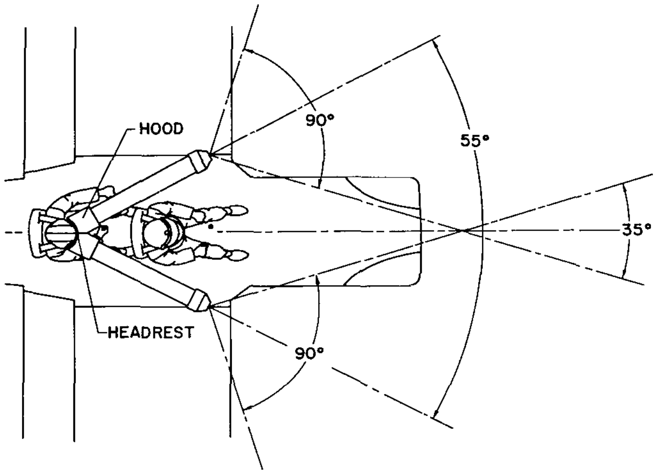

Figure 6.- Details of monocular installation.

A sheet-rubber viewing hood was attached to the rear end of the monoculars to blank out the pilot's peripheral vision. A soft-rubber headrest, which was adjusted to contact the pilot's forehead just above the eyebrows (fig. 6), prevented contact of his head with the eyepieces but did not restrict up and down or rearward head movements. The pilot was restrained in his seat by means of conventional seat belt and shoulder harnesses.

An airspeed indicator (V) and a pressure altimeter (h) were mounted to the left of the pilot as shown in figure 7. The overlap (shaded area) of the two 90° view fields is also shown in this figure.

The optical system was mounted in such a manner that the pilot's effective point of view was transferred to a position just to the rear of the windshield post (fig. 4). Thus, only a small part of the aircraft cowling was visible through the monoculars.

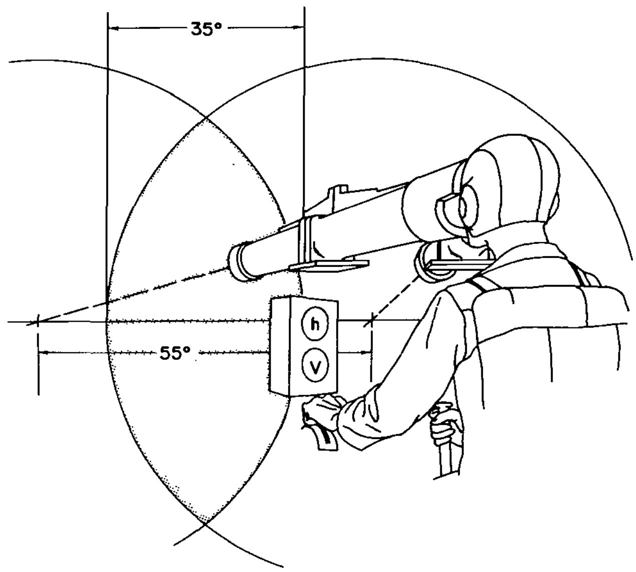

Figure 7.- Field of view and pilot's display in the test airplane.

EVALUATION PROCEDURE

Takeoffs, aerial maneuvering, visual navigation, approaches, and landings were performed by the evaluation pilot, using the optical system for all visual contact outside of the airplane. The front cockpit was occupied by a safety pilot.

Approach patterns included conventional 180° approaches, with pattern entry on the downwind leg, and 360° overhead approaches. All approaches after initial pilot familiarization were flown without power with the flaps extended 30°. The pattern-indicated airspeed was 61 knots; the lift-drag ratio in this configuration was approximately 7.

Visual navigation and aerial maneuvering were accomplished in transit to auxiliary airports used for the landing evaluations. Peak altitude for these maneuvers was 5,000 feet above the terrain; airspeeds ranged up to 100 KIAS.

Most of the evaluation was performed during daylight, with flight conditions varying from no turbulence to severe turbulence. One mission, which included six landings, was performed during the hours of twilight and darkness.

RESULTS AND DISCUSSION

The evaluation of the wide-angle optical system was based on the availability of an existent optical system which had been developed for use in armored vehicles. The weight (175 lb) and bulk of the monoculars prevented extensive adjustment of their geometry relative to the airplane.

The test airplane was selected because it afforded easy installation of the optics. Minimization of aircraft modification was a major objective.

Requirement for Pilot's Display

The first evaluation flight was made with no flight instruments available to the evaluation pilot. This configuration proved to be adequate for only the most rudimentary flying: airspeed by "feel" of the controls and altitude by estimation. An airspeed indicator and an altimeter were considered essential for the accomplishment of approaches and landings; therefore, suitable locations for these instruments were investigated.

It was originally intended to position the airspeed indicator and altimeter within the field of view of one of the monoculars. A position on the engine cowling was found which would provide adequate instrument readability without reducing the field of view; however, time limitations and required structural modifications precluded installation of the instruments at this location. A position in the rear cockpit adjacent to the left eyepiece was accepted as a satisfactory compromise. Flight experience justified this decision. It was found that the pilot could satisfactorily monitor airspeed and altitude by shifting his eyes without moving his head from the headrest.

Takeoffs and Maneuvers

Approximately 40 takeoffs were made without difficulty by the evaluation pilot. All takeoffs were from runways or marked portions of a dry lakebed; hence, the pilot had good directional reference before he became airborne. Once airborne, both directional and pitch reference became insufficient for precise attitude control because the pilot's view of the forward portion of the aircraft was inadequate for alinement with geographical features. Pitch attitude could be maintained by constant cross-reference to the airspeed indicator; intelligent sideslip corrections could be made only when transverse accelerations reached a perceptible level.

Maneuvers consisting of level, climbing, and descending turns were performed without difficulty, but with less precision than was desired. Bank angle could be estimated within 1° or 2° at all times, but sideslip could be sensed only after it reached a considerable magnitude. Pitch reference was not sufficient to maintain constant airspeed in climbs or descents by attitude reference only; constant-speed maneuvers could be accomplished only by continual cross-reference to the airspeed indicator.

Navigation

Every flight required some local-area navigation. The optics were entirely satisfactory for this task; forward and side vision were sufficient for locating the geographical features required for precise navigation. For retaining the view of terrain features passing directly beneath the aircraft, the optics compared favorably with the direct vision available from present-day cockpits.

Approaches

Initial traffic patterns were conventional 180° patterns entered from a downwind leg. The downwind-leg position could be estimated with good repeatability. Because the approach end of the runway disappeared from view before the start of the 180° final turn, the turn had to be started by estimation or by use of geographical features. Touchdown dispersion using 180° patterns averaged 1,500 feet and tended to be beyond the intended touchdown point as a result of the pilot's apprehension about landing "short" and his concomitant overcorrection. Maximum touchdown error was approximately 2,500 feet.

Overhead approaches of 360° were used with good results. Because of the reduced field of view through the optics, the high key, or overhead point, could not be located precisely. It was, therefore, determined by use of the side windows in the airplane. This procedure reduced by one the number of variables contributing to touchdown dispersion. With this outside-the-optics assistance in locating the high-key point, the remainder of the pattern could be flown using only the optics and terminated in a touchdown with an average dispersion of less than 1,000 feet. Maximum touchdown error for 360° approaches was 1,500 feet.

Landings

Thirty-eight landings on hard-surfaced runways or marked portions of a dry lakebed were attempted by the evaluation pilot using the optical system as the sole visual reference. Two approaches resulted in waveoffs prior to touchdown: one waveoff was due to the pilot's poor estimation of pattern position, which resulted in excessive altitude on the final approach; the other waveoff occurred after the flare when the evaluation pilot misunderstood the safety pilot. Six other landings required assistance from the safety pilot in the form of added power, pitch control, or directional control of the airplane after landing. All of the landings requiring this assistance occurred early in the evaluation. On at least three other landings, which were made in crosswinds, the safety pilot applied lateral control at touchdown to prevent landing in a banked attitude, but allowed the evaluation pilot to make the flare and to control pitch attitude at touchdown. All other landings were made by the evaluation pilot without assistance and with generally increasing proficiency.

The pilot at no time had difficulty judging when to initiate the flare. Knowledge of the size of runway markings provided adequate cues.

Loss of height information occurred after the flare. On all daylight landings, it was impossible to judge height when just above the runway. Thus, there remained no recourse but to establish a landing attitude and accept whatever rate of sink occurred at touchdown. Touchdown dispersion about selected landing points, discussed in the preceding section, was determined by pilot technique and judgment during the approach pattern and was relatively independent of the landing technique.

The reason for the loss of height information after the flare was not definitely determined. Two probable causes were: (1) bioptic vision of the runway texture was not available to the pilot because the airplane cowling masked a major portion of the monocular overlap area, and (2) normal peripheral vision was not available to the pilot.

Night Flying

One flight was made during the hours of twilight and darkness. Navigation and maneuvering using the monoculars were as satisfactory during these hours as during the day. Landings were superior to those performed in daylight, primarily as a result of a red anticollision beacon on the keel of the test airplane. After the flare was performed, the height of the airplane could be accurately gaged by the intensity of the reflection of the beacon off the runway. Intelligent corrections of flight path could thus be made after the flare and prior to touchdown.

Landings were performed with and without the use of airplane landing lights. The landing lights did not noticeably improve nor detract from the pilot's ability to perform landings.

As the airplane passed runway lights on landing or rollout, moving reflections of the lights appeared in the optics similar to the reflections that appear on the windshield of an aircraft during a night landing. These reflections were objectionable during the first one or two landings, but were readily adjusted to and were not noticed by the pilot during subsequent landings.

Some light loss through the optics was perceptible but was not objectionable.

Several color aberrations were noted. Incandescent light appeared to be pale yellow instead of white, with a blue "eyebrow" above or below the light. Green light had a slight blue cast and, conversely, blue light appeared partially green. No red aberration was noted.

Effect of Air Turbulence

Flight conditions varied from no turbulence to severe turbulence. Most of the flying was accomplished in light or moderate turbulence. Under these conditions, the large exit pupil diameter (15mm) provided for sufficient head movement, so that the field of view was never restricted more than momentarily.

On one mission it was intended to perform landings at an airport experiencing high, gusty winds (25 knots with gusts to 35 knots). The approach attempted was aborted long before touchdown because the severe turbulence and severe gusts threatened safe accomplishment of a landing even by direct visual contact. Under these conditions of turbulence, there was considerable loss of view through the optics as a result of head movement. This loss was not intolerable, however, and was not a consideration in the decision to abort the approach.

Effect of Optic Inclination

There was no discernible difference in the pilot's ability to accomplish the pattern, flare, or landing with either of the optic depression angles evaluated--parallel with fuselage reference axis, and depressed 17.5°. The level optics presented a more normal view for level flight. This advantage was offset, however, by the larger area of terrain visible through the depressed optics, which presented more information for use in navigation.

Limitations of the Test Airplane

The test airplane was selected because of ease of installation of the optics. Little else recommended the vehicle for a landing evaluation. Because the main landing gear is located forward of the airplane center of gravity, any landing at less than a three-point pitch attitude results in a bounce if sink rate is appreciable at touchdown. Inherent directional instability after touchdown requires diligent pilot attention. The airplane exhibits the adverse dynamic effects typical of single-engine reciprocating airplanes (power effects) and also exhibits adverse yaw due to aileron deflection. These directional instabilities were magnified in the optics evaluation by the difficulty of visually sensing sideslip when using the optics and by the omission of the sideslip indicator from the evaluation pilot's display. This lack of sideslip indication often resulted in a "crabbed" touchdown (particularly with a crosswind), which further increased the directional instability of the airplane after landing. A sideslip indicator in the pilot's display probably would have improved the precision of aircraft control.

CONCLUSIONS

Flight tests of wide-angle, overlapping monoculars as the pilot's sole source of outside visual reference in a light observation airplane resulted in the following conclusions:

1. The monoculars provided adequate visual reference for gross control of pitch and sideslip angles and for precise control of bank angle.

2. When used in conjunction with an altimeter and airspeed indicator, the monoculars provided the pilot with adequate information to satisfactorily perform takeoffs, visual navigation, mild aerial maneuvers, and power-off approaches through the landing flare. Inclusion of a sideslip indicator in the pilot's display would probably have improved the precision of aircraft control.

3. Loss of height information after the flare did not preclude accomplishment of landings. It did, however, allow considerable variation in rate of sink at touchdown and noticeably reduced the precision with which the landings were accomplished.

4. The monoculars were as suitable for outside visual reference during night operation as during the day. Reflection off the runway of light from an anti-collision beacon on the keel of the test airplane provided height information after flare during night landings. Thus, landings were made at night with more precision than during the day.

5. The exit pupil diameter (15mm) of the optics was sufficient to accommodate the pilot's head movement during flight in light and moderate turbulence without loss of field of vision, but was only marginally sufficient for flight in severe turbulence.

6. There was no discernible difference in the pilot's capability to accomplish the pattern, flare, and landing with the optics parallel to the fuselage reference axis or depressed 17.5°. A larger area of terrain was visible through the depressed optics, which presented more information for use in navigation.

RECOMMENDATIONS FOR FURTHER RESEARCH

Further research into the use of wide-angle optics in aircraft could provide a concrete contribution to reentry-vehicle design. For lifting reentry vehicle research, the most obvious follow-on program would be the installation of wide-angle optics in a high-performance jet aircraft, preferably a fighter airplane. This installation would determine the utility of wide-angle optics for landing from a high-rate-of-sink, low-lift-drag-ratio descent.

The design of the optical system evaluated herein lends itself to injection of pilot information into the optics by means of light projected onto a partially silvered mirror placed in the collimated portion of the optical path. Such control information superimposed in the field of view of the optical system should be evaluated, and pilot performance when using this control information display and when using conventional displays should be compared.

As noted previously, during night landings, reflection off the runway of light from an anticollision beacon on the keel of the test airplane provided height information after flare, thus allowing intelligent pitch corrections to be made all the way to touchdown. No such "crutch" was available for daylight landings. A high-intensity discharge light installed on the keel of a test airplane should be investigated as a height reference for daylight landings.

Study of optical-system applications to nonlifting orbital vehicles is also needed. Installation of appropriate optics in a helicopter could provide design information for rocket-assisted-landing vehicles, such as moon-landing craft.

Flight Research Center,
National Aeronautics and Space Administration,
Edwards, Calif., January 16, 1964.

APPENDIX

PRELIMINARY GROUND EVALUATION OF WIDE-ANGLE, OVERLAPPING MONOCULARS

Prior to a flight evaluation of the optical system, a preliminary ground study was conducted with monoculars made available by the U.S. Army Frankford Arsenal (ref. 1). The primary purpose of the investigation was to verify the manufacturer's specifications regarding field of vision and image presentation and to evaluate the suitability of the optics for use in an aircraft. The optical device was investigated in a target-detection problem on a ground vehicle.

DESCRIPTION AND PROCEDURE

The monoculars were mounted on the cowl of a standard Willys Jeep (figs. 8 and 9). A rubber hood at the viewer's end of the monoculars compelled the driver to use the telescopes exclusively for maneuvering. A rubber headrest was used to eliminate virtually all motion between the driver and the telescopes and to enable him to maintain the desired eye-relief distance. By moving his head downward, he could monitor the speedometer and gyro compass mounted on a panel in front of him.

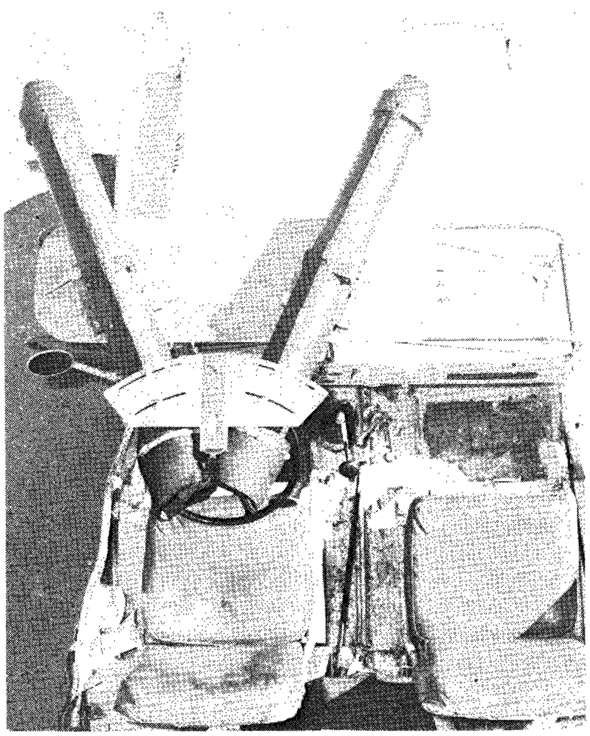

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Figure 8.- Top view of jeep installation.

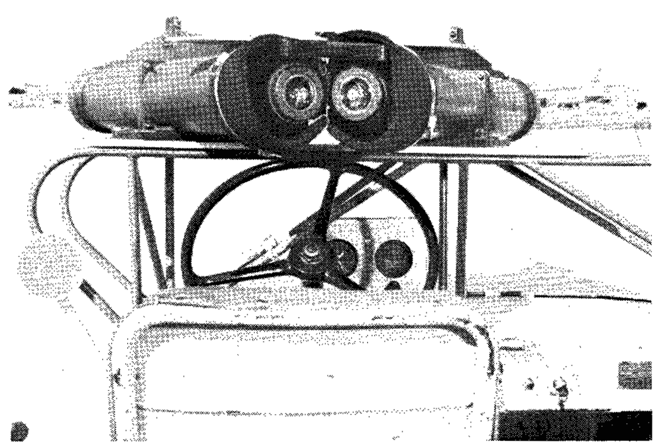

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Figure 9.- Rear view of jeep installation.

Tests were conducted using various angular separations of the optical axes. The course laid out for the ground evaluation was a 2,500-foot square on Rogers Dry Lake at Edwards, Calif. (fig. 10). Targets for the tests were numerals placed at set distances from, and angles to, the established course. The course was designed to test the field of vision, the image presentation, and the effects of different lighting conditions, ground surface conditions, and background contrast, as well as the driver's ability to maintain constant speed and heading while making observations.

The driver was requested to keep the vehicle speed at a constant 20 mph around the precisely surveyed course, with the aid of a speedometer and gyro compass. He was to identify the numerals as soon as perceived and to immediately advise the observers when the numbers disappeared from his field of view.

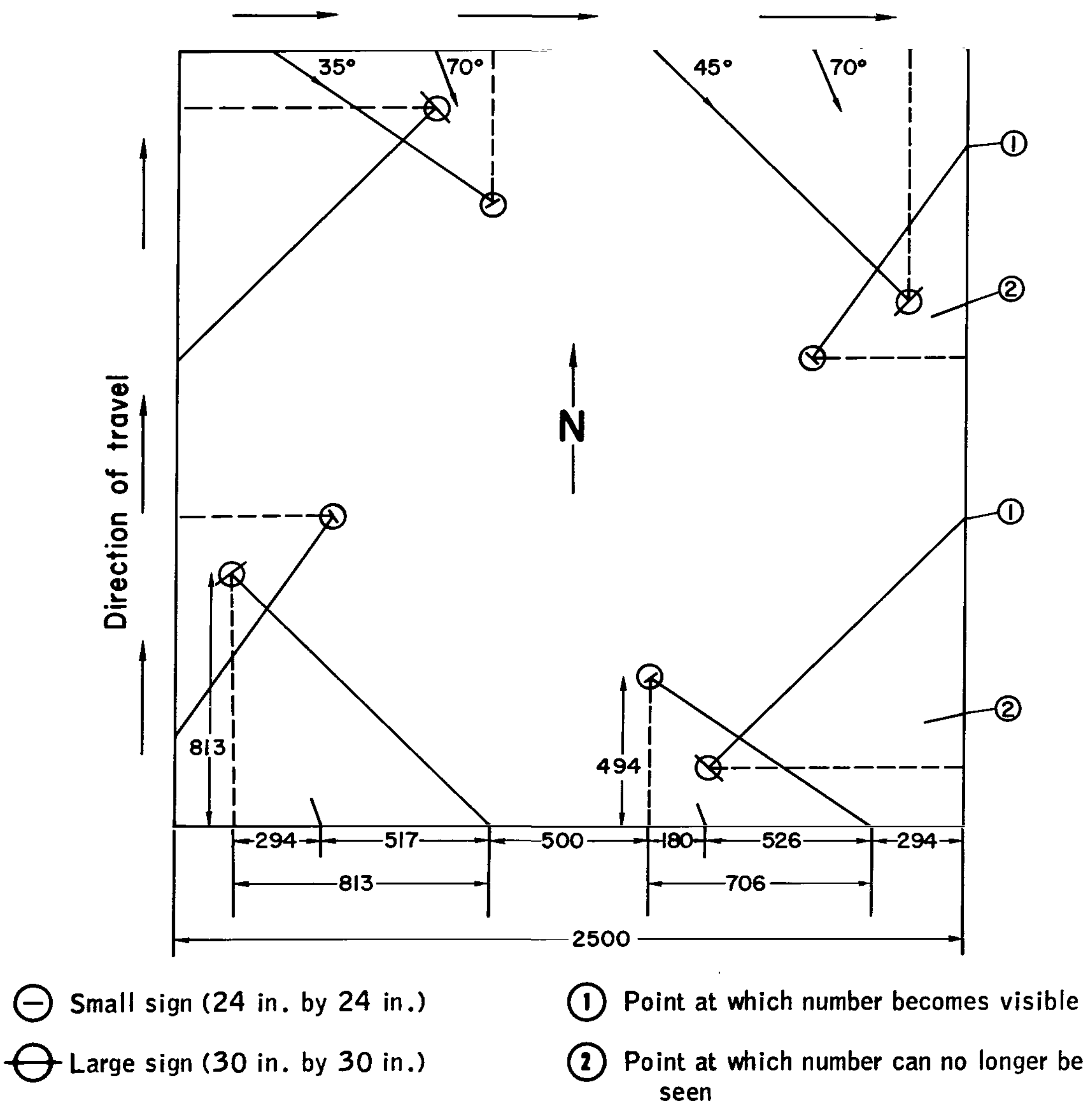

Figure 10.- Test course layout for the ground evaluation. All dimensions in feet unless otherwise specified.

SUMMARY OF RESULTS

The interpupillary separation and eye-relief distance were found to directly affect the field of view. Therefore, each driver was permitted to make necessary adjustments to fit his individual anatomy.

No distortion or color aberration could be detected; however, blurred and double vision at close range were noted in the overlap area.

A full 140° horizontal field of view was obtained with the optical axes set at an angular separation of 50°. This field of view was increased or decreased by making corresponding changes in the angular separation of the monocular axes. The drivers indicated a definite preference for a wide (as great as 60°) angular separation.

Drivers' comments indicated that the optical system compared favorably with the naked eye in providing maneuvering capability, and that there was no difficulty in identifying numerals while monitoring speed and heading.

In general, the drivers were confident that an aircraft could be maneuvered and landed if equipped with an optical configuration such as evaluated in this preliminary ground program.

REFERENCE

1. Shenker, Martin, LaRussa, Joseph, Yoder, Paul R., Jr., and Scidmore, Wright H.: Overlapping-Monoculars—An Ultrawide-Field Viewing System. Applied Optics, vol. 1, July 1962, pp. 399-402.

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